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授与した学位	博　士
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学位論文の題目	Study on Structure, Thermodynamics, and Dynamical Properties of Two－Dimensional Dusty Plasmas based on Theory and Numerical Simulations （２次元ダストプラズマの構造、熱力学、および動的特性に関する理論とシミュレーションによる研究）
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学位論文内容の要旨

The work presented in this thesis describes theoretical and numerical study on the dusty plasmas. Within the scope of this research, several aspects of the physics of dusty plasmas have been explored theoretically and numerically.

The dusty plasma system takes the single layered 2D structure at the limit of strong confinement. Such single-layered finite dusty plasma can be modeled as charged as charged particles in 2D parabolic potential interacting with each other through Yukawa potential.

In Chapter one, some fundamental notions of dusty plasmas are introduced. Behavior of dust in low pressure weakly ionized media including charging mechanism, electrostatic interactions and various forces are explained. Industrial applications of dusty plasmas are summarized. We briefly introduce dusty plasma experiment. Main motives behind this study are also elucidated in this chapter.

In Chapter two, we present the thermodynamic properties of two-dimensional Yukawa system. In the domain of weak coupling, thermodynamic quantities of 2D system of charges have different behavior because of reduced dimensionality. Mean field theory fails in this domain in 2D. But in 2D, it is important to consider both short range correlations and long-range screening even in the domain of weak coupling. Furthermore, free energy is obtained by integrating internal energy with respect to coupling parameter. It is difficult to obtain internal energy by numerical simulations in the domain of weak coupling, because of large fluctuations. Thus, the thermodynamic quantities of our system in the weak coupling domain are obtained through Mayer's giant cluster expansions. In the domain of intermediate and strong coupling we obtain the quantities through numerical simulations. Interpolation formulas are also obtained for the thermodynamic quantities.

In Chapter three, we study the structures of finite two-dimensional Yukawa system crystal theoretically. We estimate the screening length and the electric charge of experimentally observed single-layered dusty plasma reported recently based on our theoretical approach. Screening length and electric charge are measured in experiment. We apply our theory to their experiment and estimate the screening length and the charge on dust particle. We observed that the electric charge decreases and screening length slightly increases with average density.

Our theoretical approach takes into account cohesive energy and interactions between both near and far distant particles. In experiment they observed the screening length to be of the same order of magnitude as the interparticle separation. This implies that the interaction beyond nearest neighbors cannot be neglected. By implication, our estimations may be more accurate than those of experiment. Based on this analysis, for practical purpose, we derive simple formula for the estimation of these important parameters in dusty plasmas.

Many results have been published on the static and the dynamic properties of 2D Yukawa system in the domain of strong coupling through various methods. In the domain of weak and intermediate coupling basic information on the static and dynamic properties seems to be still lacking. Thus, static and dynamical properties of two-dimensional Yukawa system in the domain of weak and intermediate coupling are explored and presented in Chapter four.

We computed the radial distribution function and the static structure factor. We computed the dynamic structure factor for various coupling and screening parameters. We observe that for small wave numbers, the dynamic structure factor is dominated by contribution of the collective mode. The collective peak broadens with increase in wave number and finally merges to into the continuous spectrum of excitations which is monotone. The dispersion relations for the longitudinal and transverse collective excitations are obtained using numerical simulations.

The results are compared with those of random phase approximation (RPA) and harmonic phonons in triangular lattice. We observe that for weak coupling, our results follow those of RPA and approach those of harmonic phonons when the coupling is getting stronger. We express our results of the longitudinal mode dispersions in a simple interpolation formula.

In Chapter we concluded as: In this work, many aspects of the physics of dusty plasmas have been explored both theoretically and numerically. We have measured the screening length and electric charge on dust particle theoretically. For practical purposes, simple formulas for the estimation of screening length and the charge have been derived. We computed the thermodynamic quantities of 2D Yukawa system theoretically and numerically. Simple interpolation formulas expressing the correlation energy have been derived for the intermediate and strongly coupled system. Finally, we investigated the static and the dynamic properties of two-dimensional Yukawa system in the domain of weak and intermediate coupling. We derived simple interpolation formulas for the longitudinal mode dispersion.

論文審査結果の要旨

この論文は２次元ダストプラズマの特性を理論とシミュレーションに基づいて解析したものである。ダストプラズマは半導体製造過程などのプラズマプロセスにおいて発生する，イオン及び電子から成るプラズマ中に浮遊するミクロン程度の大きさの巨視的微粒子（ダスト）の系を指す。ダストプラズマは除去のための制御の対象としてだけでなく，プラズマのパラメータ推定，微粒子の表面加工，強結合荷電粒子系の特性の検証などを目的として研究されている。

地上では重力のためダストプラズマは一般に水平な層から成る構造をもつ。層数は鉛直方向の閉じ込めとダスト間の反発の関係で決まり，適当な条件下では，多くの実験で観測される層数１の２次元ダストプラズマとなる。ダスト間の相互作用は湯川ポテンシャルで表される。この論文では，まず，十分低温として，理論的に導かれる構造から，プラズマパラメータ推定のための内挿式を求め，具体的実験に適用して，これまでより多くの情報が得られることを示した。次に，温度の高い場合を含め，熱力学的関数を理論およびシミュレーションにより求め，結果を単純で広い範囲で成り立つ内挿式として表した。さらに，微視的な揺動スペクトルをシミュレーションにより解析し，この系の縦波の分散関係を求め，簡単な内挿式で表した。重力場中のダストプラズマはイオンの流れの中にあり，しばしば，後者の効果による不安定性が原因とされる加熱を受けることが観測されており，これらの熱力学的諸量および分散関係はこの系の基本的特性であるとともに，ダストおよびプラズマの状態の推定などに役立つ。

以上のように，本論分は２次元ダストプラズマについて学術上および応用上の重要な知見を与えており，博士（学術）の学位に値する。